THE USE OF SOLAR-POWERED TRANSMITTING VIDEO CAMERAS FOR MONITORING THE BREEDING BIOLOGY OF BEARDED VULTURES *Gypaetus barbatus*

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Abstract
We designed a system of solar-powered video cameras that transmitted images via telemetry to a monitor. This system allowed us to study the breeding behaviour of the Bearded Vulture *Gypaetus barbatus* in the Pyrenees (NE Spain). From 2000-2006, 14 nests in 8 territories were equipped with video cameras. To avoid disturbing the birds, the equipment was installed 3-8 weeks before egg-laying. The acceptance rate was 78%. No decline in productivity was observed in the nests monitored with video cameras compared to control nests. The cameras enabled us to document egg-laying, hatching asynchrony, the nestlings' diet and the parents' breeding behaviour from distances of 2-3 km, although some technical problems temporarily interrupted the transmission of images. Video cameras can be used successfully to study this species at nesting cliffs, and probably other cliff-nesting raptors, without causing a decrease in productivity.

Keywords: Bearded Vulture; Cliff-nesting raptors; *Gypaetus barbatus;* Human disturbance; Pyrenees; Video cameras.

Introduction

Obtaining detailed data on the breeding biology for cliff-nesting raptors, including egg-laying, hatching asynchrony, diet, and causes of breeding failure, can be difficult due to the limitations of the location (inaccessible cliffs) and bird sensitivity to disturbance during the breeding period (see Richardson & Miller, 1997). In this sense, the use of video cameras in the study of the biology and behaviour of different species of raptors has increased over the last decade (Kristan *et al*. 1996; Delaney *et al*. 1998; Grønnesby & Nygård 2000; Dykstra *et al*. 2002; Booms & Fuller, 2003; Margalida *et al*. 2006). In the case of vultures, very little information is available on aspects of the birds' breeding biology in the wild (see revisions in Mundy *et al*. 1992), and in some species, the majority of the detailed information comes from captive individuals (e.g. Mendelsshon & Leshem, 1983). For threatened species, conservation priorities take precedence and thus human activities should be avoided in the area surrounding the nest (e.g. Steidl & Anthony, 2000). Such is the case for the Bearded Vulture *Gypaetus barbatus*, an endangered species, which inhabits European mountain ranges including the Pyrenees and the Alps (after their reintroduction in 1986), and the islands of Corsica and Crete. There are 122 breeding pairs in the European Union, 80% of which are in the Pyrenees (Heredia & Margalida, 2003). The Bearded Vulture is a territorial cliff-nesting accipitrid vulture whose diet basically consists of bones (Hiraldo *et al*. 1979). It is a long-lived species (Brown, 1997) characterized by late sexual maturity and a prolonged breeding cycle, beginning in September-October with the rebuilding of the nests (Margalida & Bertran, 2000b) and ending in June-July, when young fledge (Margalida & Bertran, 2000a; Margalida *et al*. 2003). Laying takes place in December-February and the incubation period is 54 days. The nestling period is about 4 months (Margalida *et al*. 2003). The Bearded Vulture's average productivity in the Pyrenees is less than 0.5 chicks/pair/year (Heredia & Margalida, 2001; Margalida *et al*. 2003), and appears to be very sensitive to human disturbance (Layna & Rico, 1991; Donázar *et al*. 1993).

We developed a radio-frequency-linked mini-camera system that transmits a video signal for documenting lesser known aspects of the Bearded Vulture's biology, which will help improve the application of conservation measures (e.g., rescuing the second nestling to increase productivity or to create a stock for captive breeding and studying the species' diet to improve the functioning of feeding stations). We tested this system during six consecutive breeding seasons, between 2000 and 2006, at 14 Bearded Vulture nests in a total of 8 territories. Herein, we describe the monitoring system (see also Margalida *et al*. 2006) and results after six years of study in order to analyze its advantages and disadvantages in their application for this and/or other vulture species.

Material and Methods

The study was in the Catalan Pyrenees mountains (NE Spain). This area contains 31 Bearded Vulture territories, of which 22 are breeding territories. The average maximum and minimum temperatures within the study area are 30ºC (July) and –5ºC (January), respectively. The average annual precipitation is over 800 mm, with 78 days of precipitation annually, which falls mainly as snow between December and February. The study area's terrain is rugged, which makes access to the nests difficult, and the average distance between nests and the nearest track is over 500 m. In the study area, the average elevation at which the Bearded Vultures nest is 1,387 ± 363.5 m (range 650-2,130 m, n = 48) and the average number of nests per territory is 4.7 ± 2.6 (range 2-11 nests, Margalida & Garcia, 2002).

The nests were located and monitored during September and October, when Bearded Vulture's nest-building begins (Margalida & Bertran, 2000b). Each year during the pre-laying periods (October-December), we installed two-three video camera systems in separate Bearded Vulture territories. The nests monitored with video cameras were situated at elevations between 900 and 1,650 m. The cameras were installed on the roofs of the cavities to provide a view of the inside of the nest and sufficiently high so as not to disturb the birds. The transmission system was installed on top of the cliff on eleven occasions and, on three occasions, at the bottom of the cliff. The average distance between the nest and the transmission system was 36.7 m ± SD = 21.1 (range 15-80 m, n = 12, Margalida *et al*. 2006).

The camera system (for more details see Margalida *et al*. 2005b, 2006) included transmitting equipment (a video camera and a transmitting antenna, powered by a solar panel or a wind-powered battery charger in one of the nests, and battery) and receiving equipment (a receiving antenna and a video recorder with a color monitor). The cost of the one complete system was approximately 4,200 €. The miniature video camera Panasonic measured 89 x 26 mm. It used a 12-volt power source (all components are 12 volt unless otherwise noted) and operated on a current of 100 mA. The camera was connected to a 2.4 GHz, water-resistant radio transmitter. The radio transmitter operated on a current of 180 mA. A small 50 x 10 mm microphone was connected to the transmitter. The camera and the transmitter were fixed to a wall using metal rock climbing materials (bolts). The transmitter was fixed using a 1-m aluminium support that allowed it to be pointed in the required direction (receiving equipment). The camera was connected to the transmitting antenna using a coaxial audio-visual cable, and the transmitter was connected to a power unit situated above or below the cliff using coaxial cable.

The power unit (battery) was attached to the support frame for the solar panels, which supplied the energy required by the transmission system. This power unit was a light sensor with a voltage of about 12 volts, and operated using a current of 5-60 mA. The light sensor was 65 x 45 x 30 mm and was connected to a solar regulator (P262-2), which operated on a current of approximately 0.1 mA (size 105 x 95 x 140 mm). It was connected to the Siemens solar panel with a nominal voltage of 15.5 volts, which were 1200 x 527 x 63 mm in size. This device charged the lead battery, and was 151 x 98 x 97.5 mm in size. The battery reserve capacity lasted for 3-4 days without sun and, if a deep discharge occurred, it took 3 hours of sunlight to recharge it completely. In one of the nests we used a wind-powered battery charger with an adapted volt regulator, which was 910 mm in diameter and 608 mm long, fixed to a 2m high mast. The image was received by an antenna programmed using the same frequency as the 2.4 GHz transmitter, which could be received at 1,000 m away. Line-of-sight was required between the transmitting and receiving antenna. The battery was powered using an audio-visual cable connected to one video recorder Sony mini DV format image receiver with a color, 148 x 62 x 135 mm LCD monitor, with its own battery or else connected directly to a 12-volt lead battery.

Results

From 2000-2006, 18 Bearded Vulture nests in a total of eight territories were monitored with video cameras. The equipment was installed 3-8 weeks before egg-laying. The average time it took to install the equipment in a nest for the first time, once we had reached the nest cliff, was 3.4 ± 1.2 h (range 2.2-6.4 h, n = 12, Margalida *et al*. 2006). This time depended on the cliff height and the climbing difficulty.

To monitor the 14 breeding attempts, a total of 18 camera systems were installed, which implies an acceptance rate of 77.8%. This was a result of some pairs changing nests. Of the 18 cameras installed, 12 were camouflaged with natural materials present in the nest (e.g., wool) and no camouflage was used with the remaining six. Although there are few data, it appears that the camouflaged systems were more readily accepted (83% vs. 50%).

We documented successful breeding at 9

(64.3%) of 14 camera systems that were installed and then accepted by the birds. In two of the remaining six cases, the pair did not lay eggs and in the third case the camera system was removed after the birds changed nest, for reasons probably unrelated to the presence of the cameras because this pair generally rebuilt several nests before egg-laying (pers. obs.). In this case, after the camera system was removed, the pair changed nest three more times and finally breed successfully. In the fourth case, during the incubation period the egg was rescued after it was seen that human disturbance was putting it in danger. This egg was incubated successfully in captivity; the chick hatched and then became part of the captive stock. In the remaining two cases, breeding failure takes place during the incubation period.

Productivity

The productivity of Bearded Vultures at occupied camera nests during the period 2000-2006 was 0.64 young/breeding attempt (*n* = 14) and at control (undisturbed) nests during the same period was 0.43 young/breeding attempt (*n* = 101). If we consider all the nests in which camera systems were installed (*n* = 18), the productivity was 0.5 young/breeding attempt. Thus, cameras did not negatively affect the reproduction of pairs. The cases of breeding failure documented (*n* = 5) took place during the incubation (three cases related to infertility of the eggs and nest-abandoning), hatching (one case) and chick-rearing (one case in which the chick died at age of 4 days).

System Performance and Problems

The camera system allowed us to document the egg-laying intervals (6 days on average, range 5-7, *n* = 7), time and incubation behaviour (53.4 days on average, range 52-55 and a median of prolonged incubation in the case of infertile eggs of 25 days, range 10-73, *n* = 10), hatching asynchrony (6.5 days on average, range 5-8, *n* = 6), sibling aggression (the age at which the second chick died varied from 4-9 days) and diet (for more details see Margalida *et al*. 2004, 2005). Image quality was good and only influenced by lighting conditions during direct sunlight (overexposure of the image made prey identification difficult). For example, the effectiveness of the system was demonstrated by the fact that that we were able to document the hatching interval (defined as the time elapsed in hours between the first observation of a hole in the egg until the time the chick was seen to be completely free of its eggshell) and all feeding bouts and aggression between siblings (Margalida *et al*. 2004). In addition, in three focal pairs in which a study of diet was carried out, 309 (87.8%) prey items could be identified out of 352 delivered to the nests.

During the second two weeks of December and the first two weeks of January (days with the lowest number of daylight hours), images could be received for 9 h (from 7.30 to 16.35) and 10 h (from 7.10 to 17.12), respectively. The number of hours during which the images were received increased as the number of daylight hours increased (e.g., 10.4 h during the first two weeks of February and 12.2 h during the first two weeks of March). Cloudy conditions influenced the number of daylight hours in which images could be received, varying between a few minutes and half an hour.

In two of the cameras, temperature fluctuations or precipitation caused condensation. Condensation occurred on the camera lenses during the months of December, January and March and between 11.00 and 16.00. Because this period coincided with the incubation period it was not possible to change the camera. In another camera, a mammal (possibly a Beech Marten *Martes foina*) chewed through the camera cable and disrupted the video signal for two months. The replacement of the camera was carried out during the second month of the nestling period, during which the chick remains alone for 15-20% of daytime (Margalida & Bertran, 2000a). In five cases, gentle movements were detected in the camera, which moved the lens focal point slightly. One of them was caused by the fact that the roof of the cavity was very close to the nest, which allowed the adults to go up to the camera and collect the wool camouflage for their nest. In the other four cases, the causes of the movement were unknown, although they might have been related to a problem with the camera ball-and-socket mount. In the first two cases, this occurred during the pre-laying period and could thus be corrected. In the third case, the movement was detected during incubation, but because it was very slight it did not prevent data from being gathered. In two more cases, movement of the focal point was detected during the nestling period. In one of them, we went to the nest while the adults were absent to correct the camera system, while in the other case it was not necessary to intervene. Finally, in two of the camera systems, the wind ripped off the solar panels, interrupting the transmission of the signal. These panels were replaced and it was then possible to continue the monitoring without any problems.

The system transmission was planned to be received within a 1-km radius. Nevertheless, the system was tested successfully at 3.5 km, and, although the quality of the images was lower, it was sufficient for the purposes of this study (e.g. to document laying intervals, hatching asynchrony), including prey identification. During the third year, several problems were detected in one of the transmitters, which were attributed to the material wearing out. This problem caused the transmission distance to be reduced to < 600 m. Wear on the batteries also caused problems and led to intermittent reception of images in two of the cameras during the third year of monitoring and in another camera during the fourth year. Low temperatures and constant recharging probably affected the life of the batteries.

Discussion

The results show that in the Bearded Vulture, a species very sensitive to human disturbance (Layna & Rico, 1991; Donázar *et al*. 1993), the final acceptance of the camera system apparently does not constitute an intrusive method of studying their breeding behaviour. The acceptance rate is higher than the rate of 65% obtained by Dykstra *et al*. (2002) for Bald Eagles *Haliaeetus leucocephalus*, a percentage considered by these authors as non-intrusive. Although some pairs changed nests, this behaviour has also been observed in undisturbed Bearded Vultures because this species can rebuild several nests before choosing the definitive site, so cameras probably have less effect than it might seem and are probably not responsible for the changes that were observed. In addition, in the study area the percentage of pairs that did not begin laying was on average 25% (n = 119 breeding attempts, Margalida *et al*. 2003), which means that the fact that they did not lay eggs was not necessarily directly related to the presence of the camera.

The effects of installing cameras in raptor nests during incubation or nestling periods vary from one species to the other. In the Bald Eagle, for example, results ranging from a high rate of nest abandonment (Cain, 1985) to successful nesting similar to those recorded in undisturbed nests (72% vs. 75% respectively, Dykstra *et al*. 2002). It appears that this species' reaction was related to the breeding period in which they were installed, the distance from the nest, or the birds' habituation to humans (Cain, 1985). However, in other species, such as the Peregrine Falcon *Falco peregrinus* (Enderson *et al*. 1972) and Osprey *Pandion haliaaetus* (Steidl *et al*. 1991; Kristan *et al*. 1996), no negative reactions were observed. The disadvantages of disturbance may be avoided or reduced by installing the system during the pre-laying period. In the case of the Bearded Vulture, nest-building behaviour takes place 2-4 months before egg-laying (Margalida & Bertran, 2000b), which facilitates locating nests well before the laying starts. Other advantages associated with installing the camera systems during the pre-laying period are: 1) it allows biologists to check whether the equipment disturbs the birds, and may allow the birds to become accustomed to the material and to accept its presence before breeding begins; 2) it allows biologists to check that the system works properly and leaves enough time for them to intervene if technical problems are detected or if the birds change nests. Moreover, the autonomy of our system allows the study to be carried out without having to visit the nest area after it has been installed (except in the case of technical problems). This reduces the potential negative effects the presence of a researcher would have on the breeding effort.

The camera systems permitted us to study aspects of Bearded Vulture's breeding behaviour (see Margalida *et al*. 2002, 2004, 2005) without causing a decrease in productivity. For example, for the study of the diet we identified 81.5% of the observed remains in the nest and 88% of prey delivered, a higher percentage than that obtained using telescopes (55.1% and 88.2% respectively, Margalida *et al*. 2005a). Similar results were obtained by Booms & Fuller (2003) in the Gyrfalcons *Falco rusticolus* (95%) with time-lapse studies in the same species. This percentage is important when considering that the Bearded Vulture brings in fragments of bone and half-consumed animal remains, which are very difficult to identify. Although this system involves a greater investment of time, because it means the researcher has to be present during the recording (the recording capacity of the tapes is only 90 minutes), it also has a series of advantages, such as: 1) a single receiving system can be used to monitor different nests, because it is easy to carry about; 2) it is no more expensive, since it avoids having to use and check countless tapes, as occurs in other types of studies; 3) it allows the interactions that occur around the nest (< 500 m) to be documented and this behaviour to be associated with what is going on inside the nest. Nevertheless, although the automatic recording system has also been used, a notable improvement in our system would be the replacement of the video-recording system by a computer hard disk (authors, unpubl. data) or a video-recording system that covered all daylight hours (> 14 h).

The disadvantages of the video system are mechanical failure, and the cost and time invested in monitoring. The problems related with mechanical failure can be resolved by increasing the capacity of the batteries, the size of the solar panels, the use of wind-powered battery chargers and repellents to avoid carnivores interfering with the equipment. In order to fix any technical problems without disturbing the birds, it is advisable to situate the transmission and power systems away from the nest and to ensure that they cannot be seen from the nest (installing them at the bottom of the cliff, for example). Regarding solar power, Booms & Fuller (2003) caution that this system may not be as reliable in non-arctic climates or in seasons when less sunlight is available. One solution to this problem, applied experimentally to the Bearded Vulture, is the installation of wind-powered battery chargers. These devices can replace the solar panels and can be especially effective in cliffs facing north, which receive little sunlight. In addition, wind-powered battery chargers permit the use of infrared cameras, allowing the batteries to be recharged at night. Concerning the time invested in monitoring, the use of other systems that permit 24 h recording time (e.g. Sony SVT-DL224 time lapse VCR, Booms & Fuller, 2003) would improve the efficiency of the system.

Although some camera systems can work perfectly for several years, it is wise to change the batteries annually and renew other parts such as the camera, the transmitter or the light sensor every three years. Thus, the cost of each system for monitoring other nests (the transmission alone) would be 1,950.00 €. The three-year renewal of the replacement components most likely to fail is about 825.00 €.

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